



Societal Benefits Analysis

Societal Benefits Topic Team Public Meeting

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SCAQMD Diamond Bar, CA

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Acknowledgement

- The Societal Benefits Topic Team's efforts are based on the participation of 33 individuals
- Private firms, non-governmental organizations, CA Universities, CA state agencies, energy companies, automakers, AQMD's, and DOE/Sandia National Lab.



$$\left[\frac{p^2}{2\mu} + V(r) \right] \psi(r) = E \psi(r)$$

California Hydrogen Highways

www.hydrogenhighway.ca.gov

Outline and Objective

- Hydrogen Pathways and Applications
- Energy inputs and GHG emissions
 - Approach
 - Societal Benefits Ratings
- Criteria pollutants
 - Approach
 - Societal Benefits Ratings
- Conclusions

From an environmental standpoint, consider pros/cons of various hydrogen production methods. CA H2Net Implementation Plan



$$\left[\frac{p^2}{2\mu} + V(r) \right] \psi(r) = E \psi(r)$$

8 Baseline pathways

Energy Carrier	Central Plant Production	Delivery	On-Site Production
Renewable Power			Electrolysis
	Electrolysis	Tube trailer	
Grid Power			Electrolysis



All pathways include compression to 6250 psi.⁷²

8 Baseline pathways

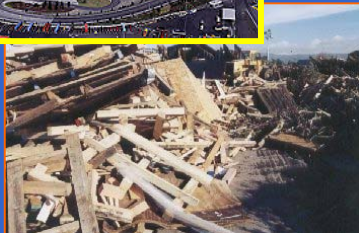
Energy Carrier	Central Plant Production	Delivery	On-Site Production
Renewable Power			Electrolysis
	Electrolysis	Tube trailer	
Grid Power			Electrolysis
Natural gas	Steam reforming, Existing LH2 plant	LH2 Truck	
	Steam reforming	Mobile fueler	
			Steam reforming



All pathways include compression to 6250 psi. 7672

8 Baseline pathways

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Renewable Power			Electrolysis
	Electrolysis	Tube trailer	
Grid Power			Electrolysis
Natural gas	Steam reforming, Existing LH2 plant	LH2 Truck	
	Steam reforming	Mobile fueler	
			Steam reforming
Petroleum Coke	Gasification to H2	Mobile fueler	
Biomass (Ag waste)	Gasification to H2	Mobile fueler	



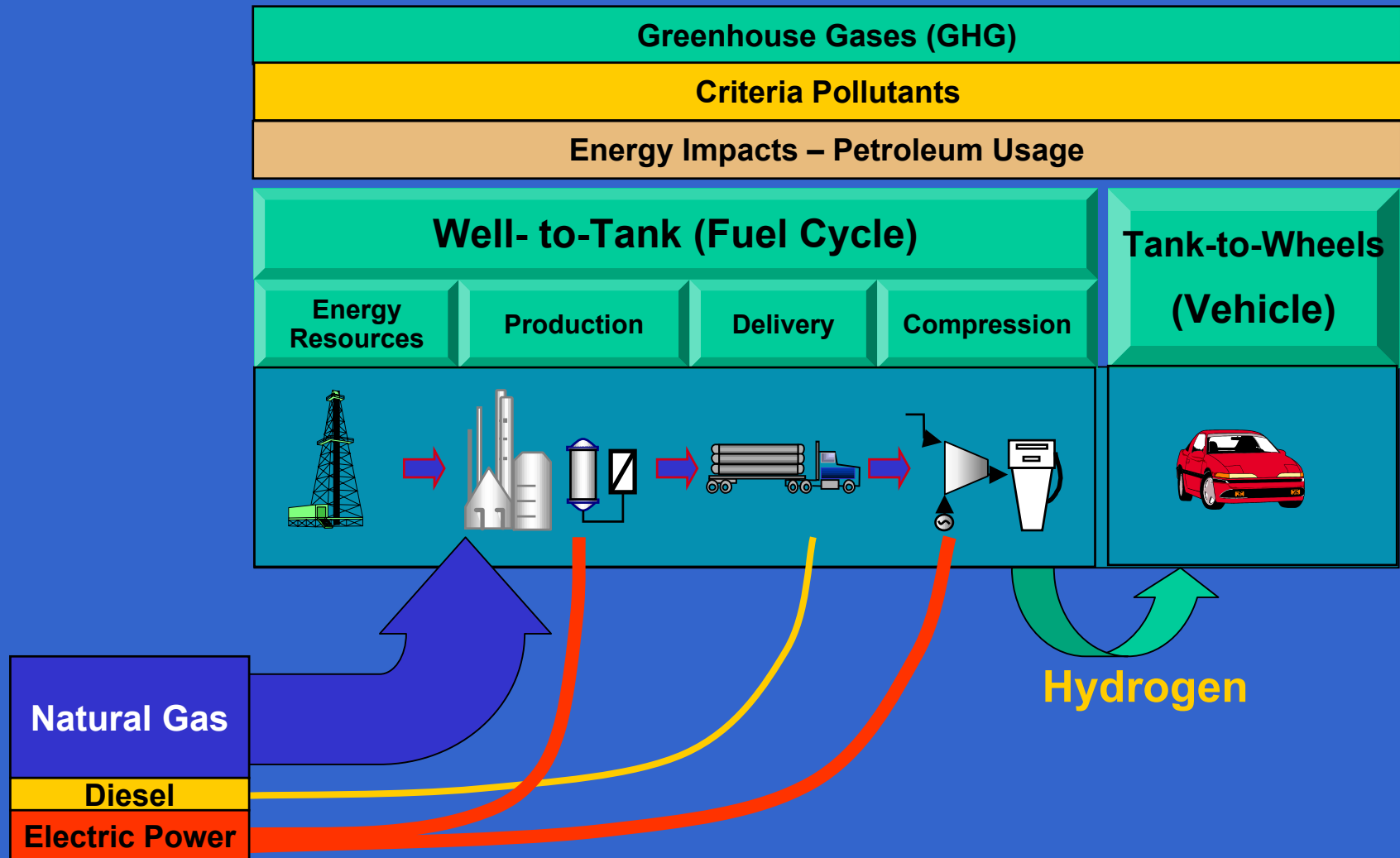
All pathways include compression to 6250 psi⁷²

Hydrogen Applications

- Passenger cars
 - Fuel cell
 - Internal combustion engine
- Buses
- Stationary power
 - Fuel cell
 - Internal combustion engine
- Other

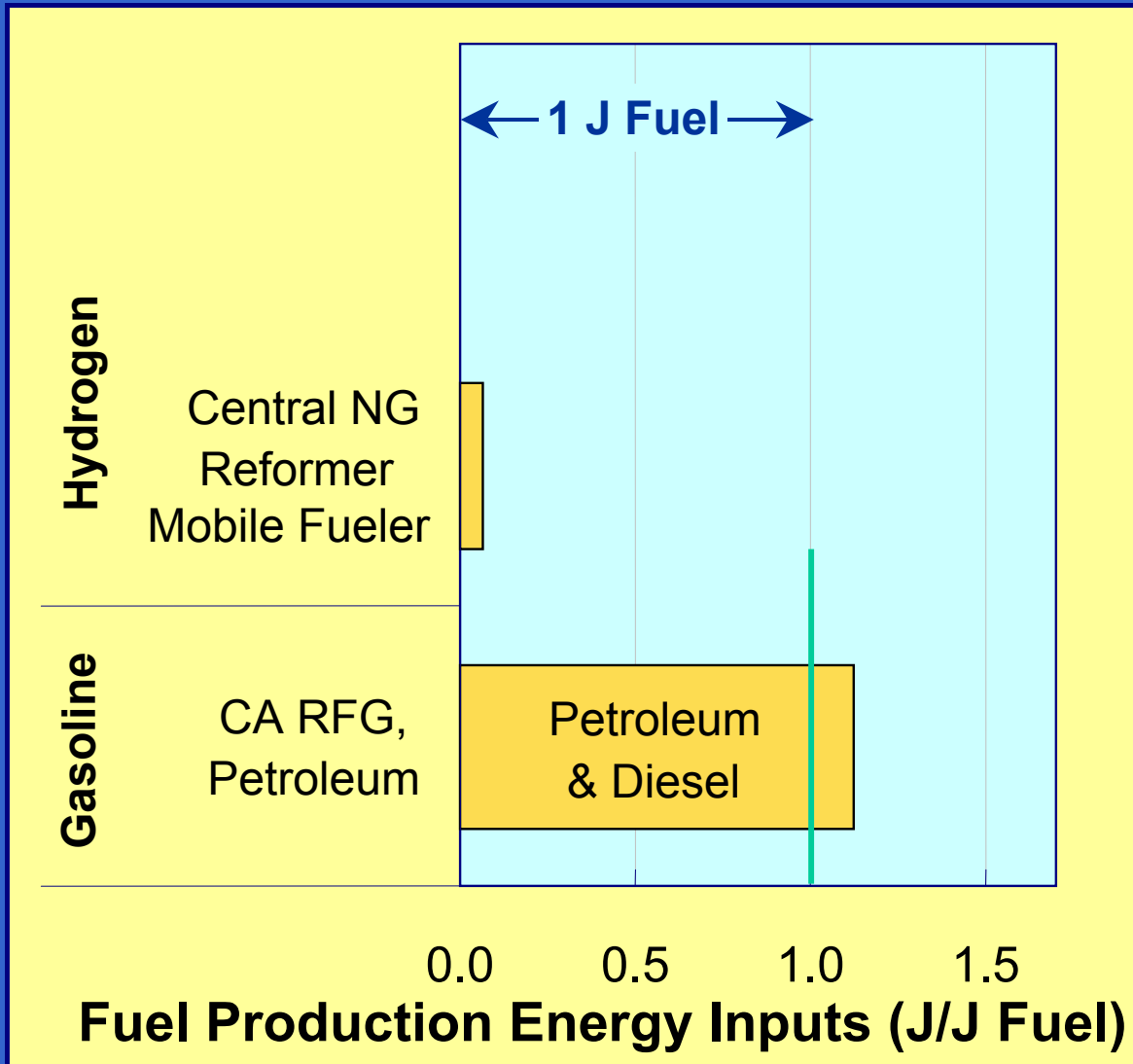


Well – to – Wheels Fuel Cycle Analysis



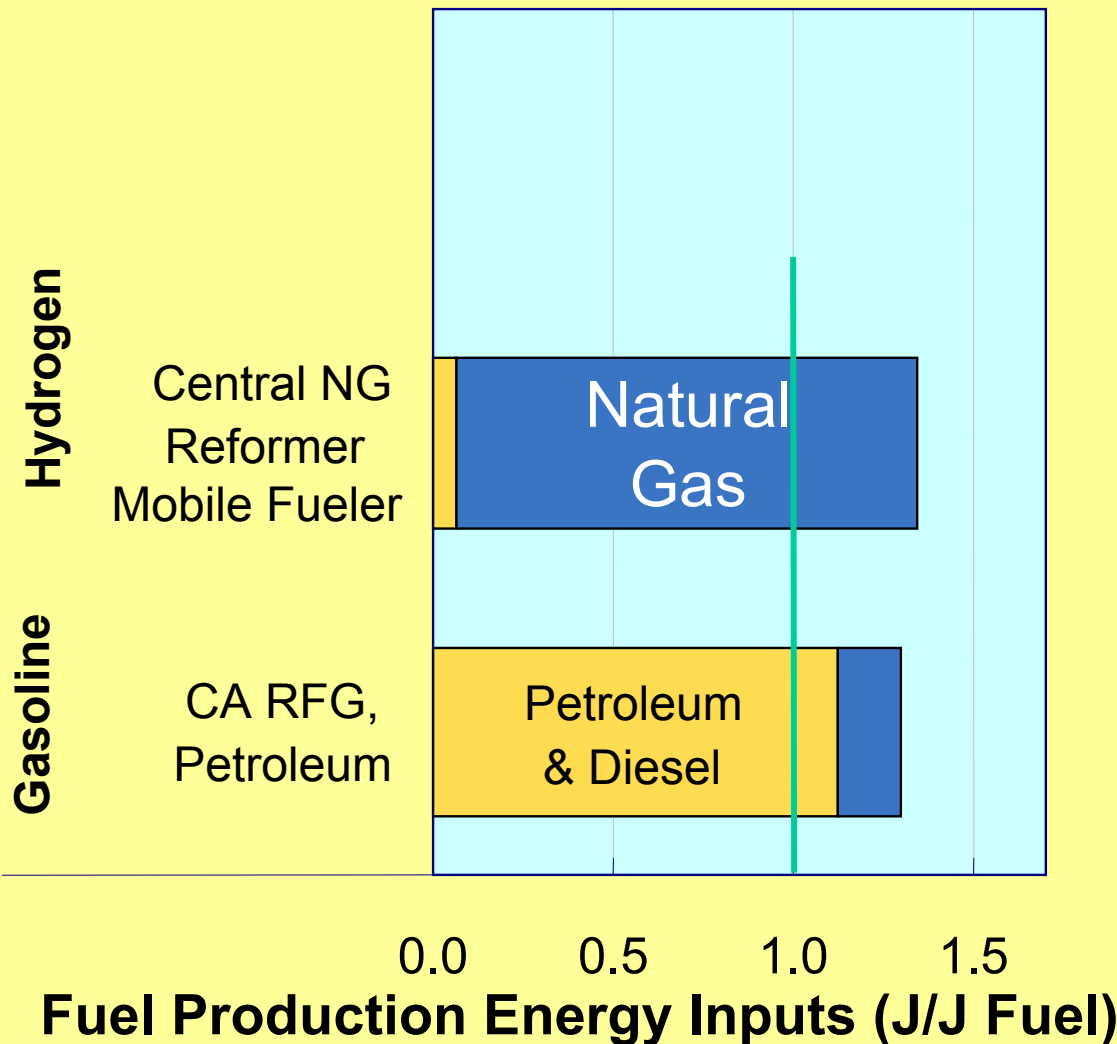
Example: Central Natural Gas Steam Reformer ⁷⁶⁷²

Energy Inputs



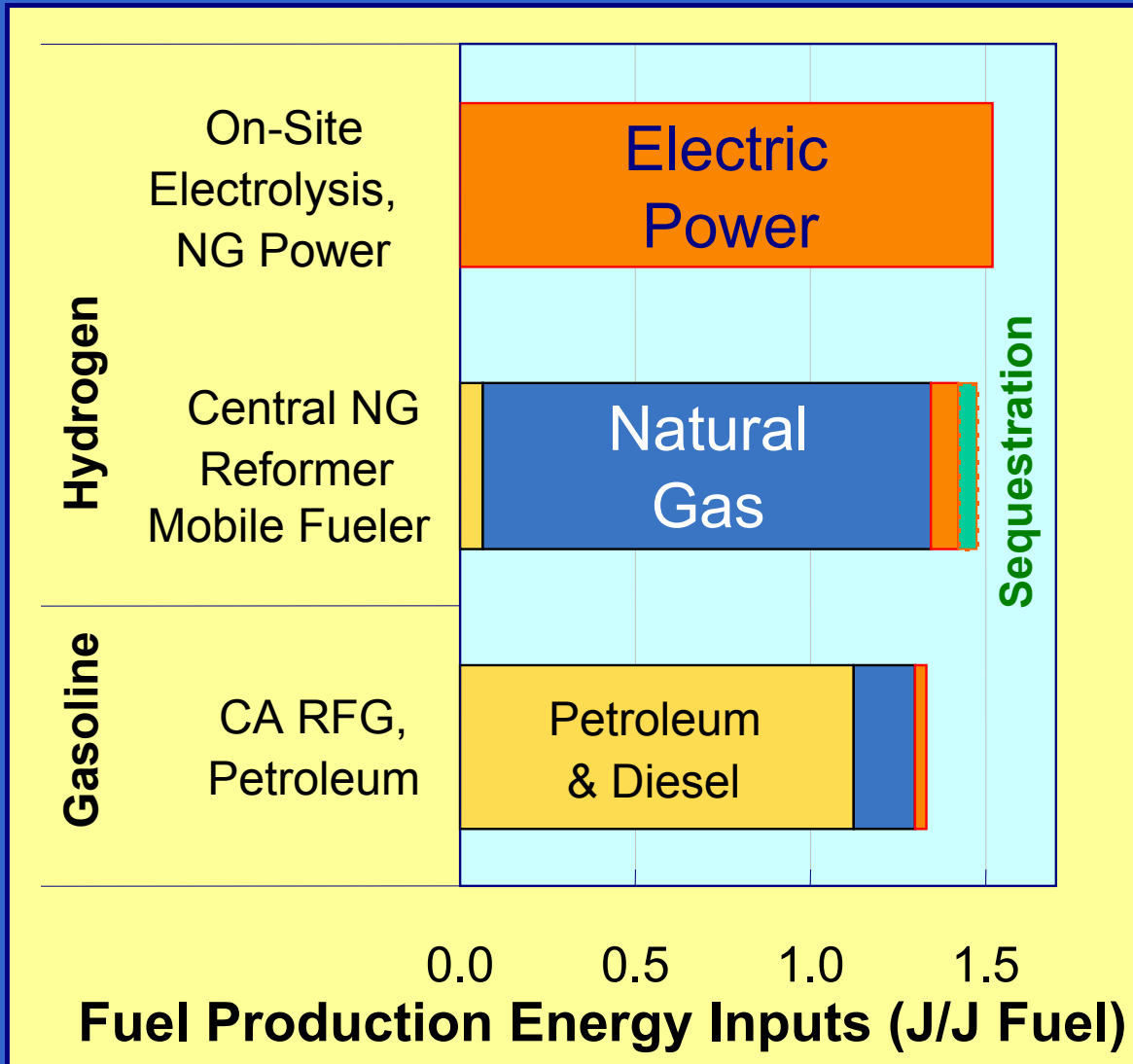
- Fuel production and distribution energy
- Petroleum

Energy Inputs



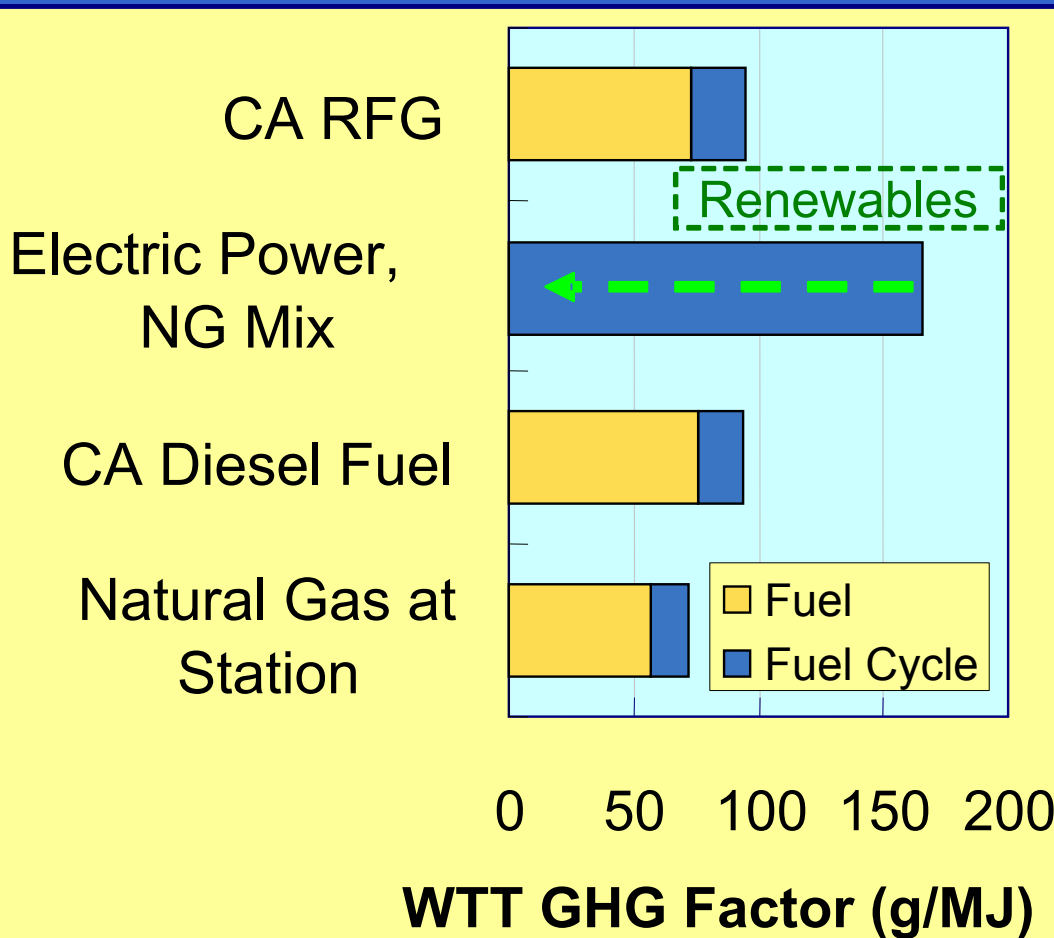
- Fuel production and distribution energy
- Petroleum
- Natural Gas

Energy Inputs



- Fuel production and distribution energy
- Petroleum
- Natural Gas
- Electric Power

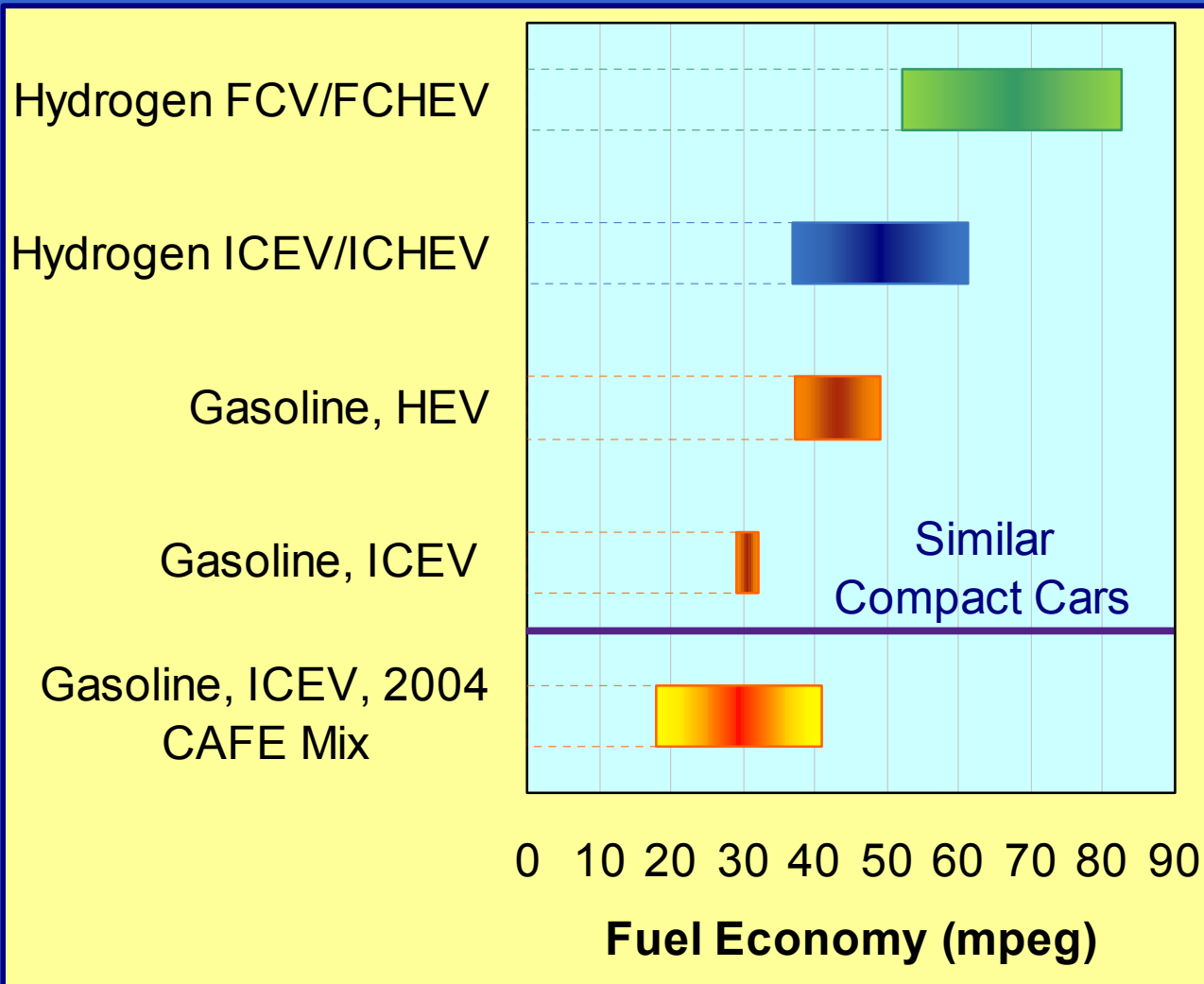
Well – to – Tank GHG Factors



- WTT energy and GHG for CA use
- Fuel GHG depends on carbon content
- Renewable power can be used for various pathways

WTT GHG factors calculated using GREET 1.6 for CA transportation distance and fuel specifications. GWP Weighted GHG, CO₂=1.

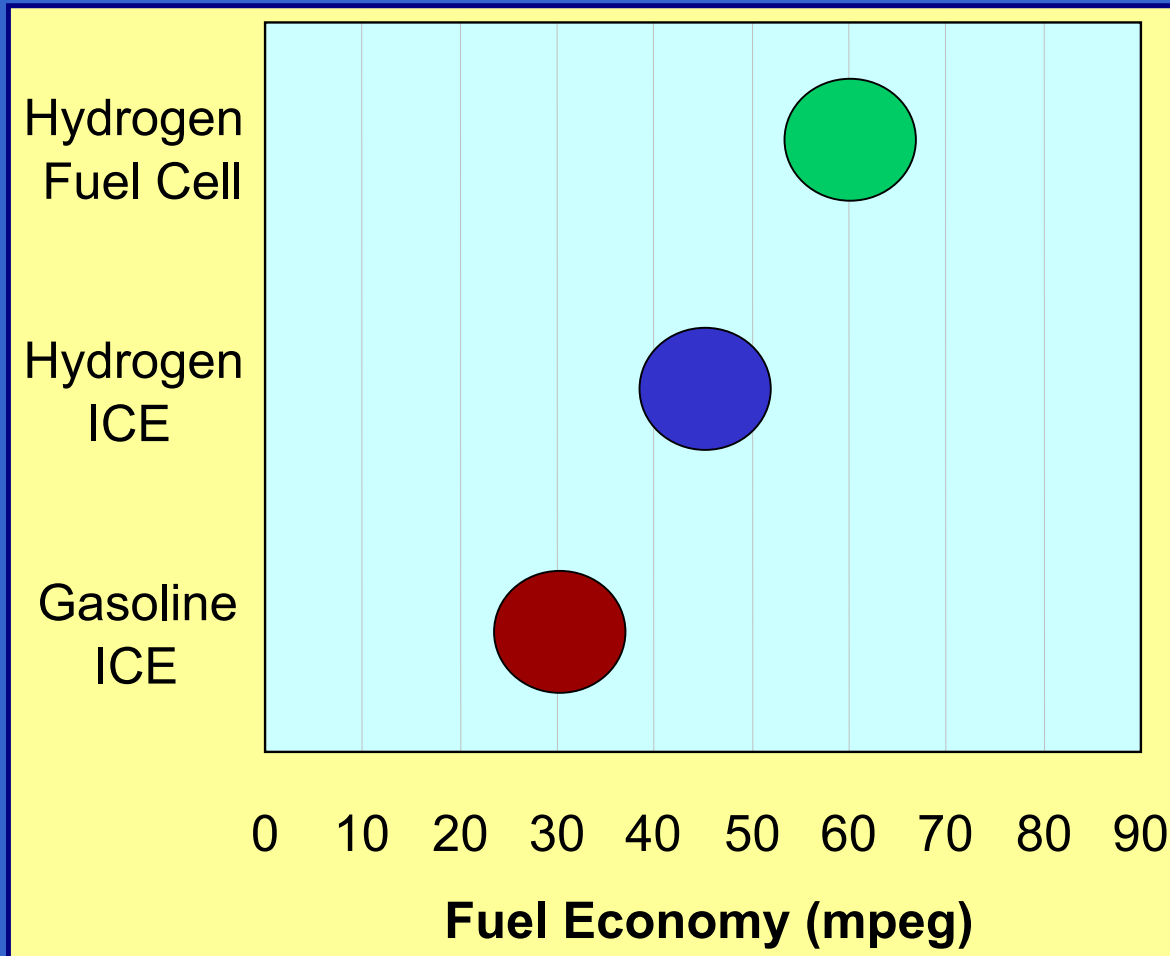
Passenger Car Fuel Economy



Improved Fuel Economy

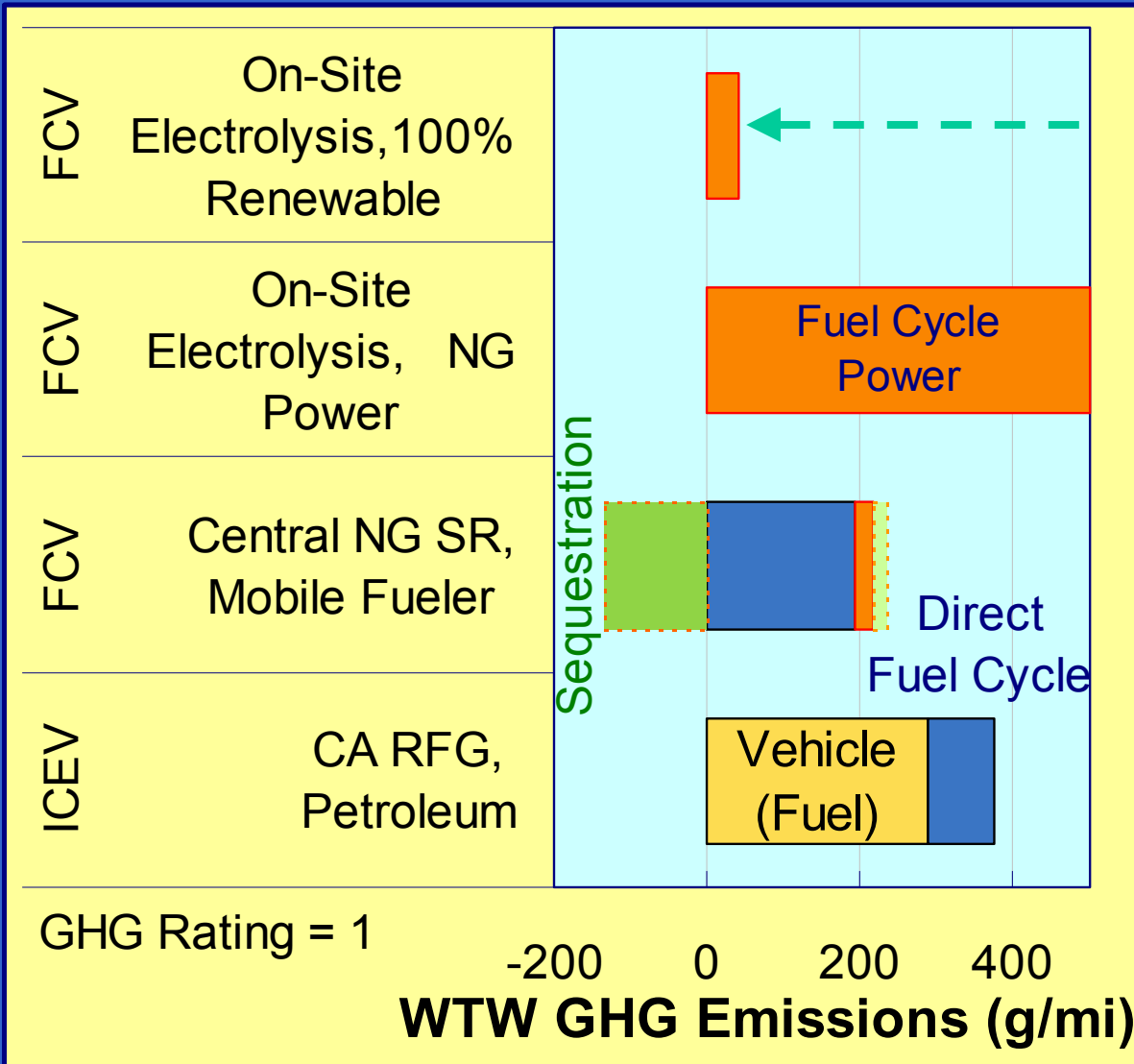
- Hybridization
- Hydrogen engine
- Hydrogen fuel cell

Baseline Fuel Economy



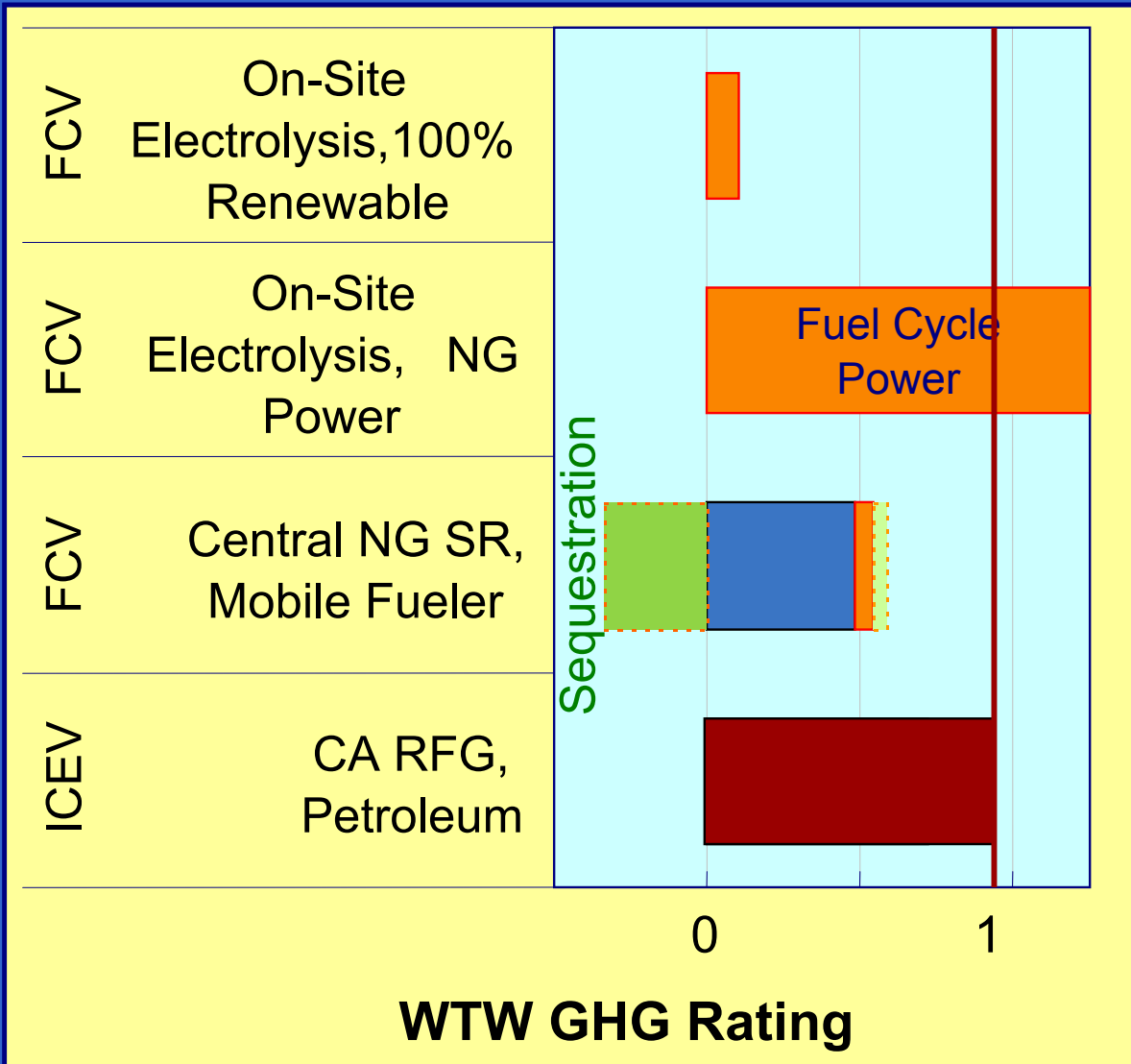
- Fuel economy values used in Societal Benefits Rating
- Similar vehicles

WTW GHG Emissions



- Fuel production, distribution, and vehicle
- Sequestration
- Vehicle exhaust
- Convert to GHG rating

WTW GHG Rating

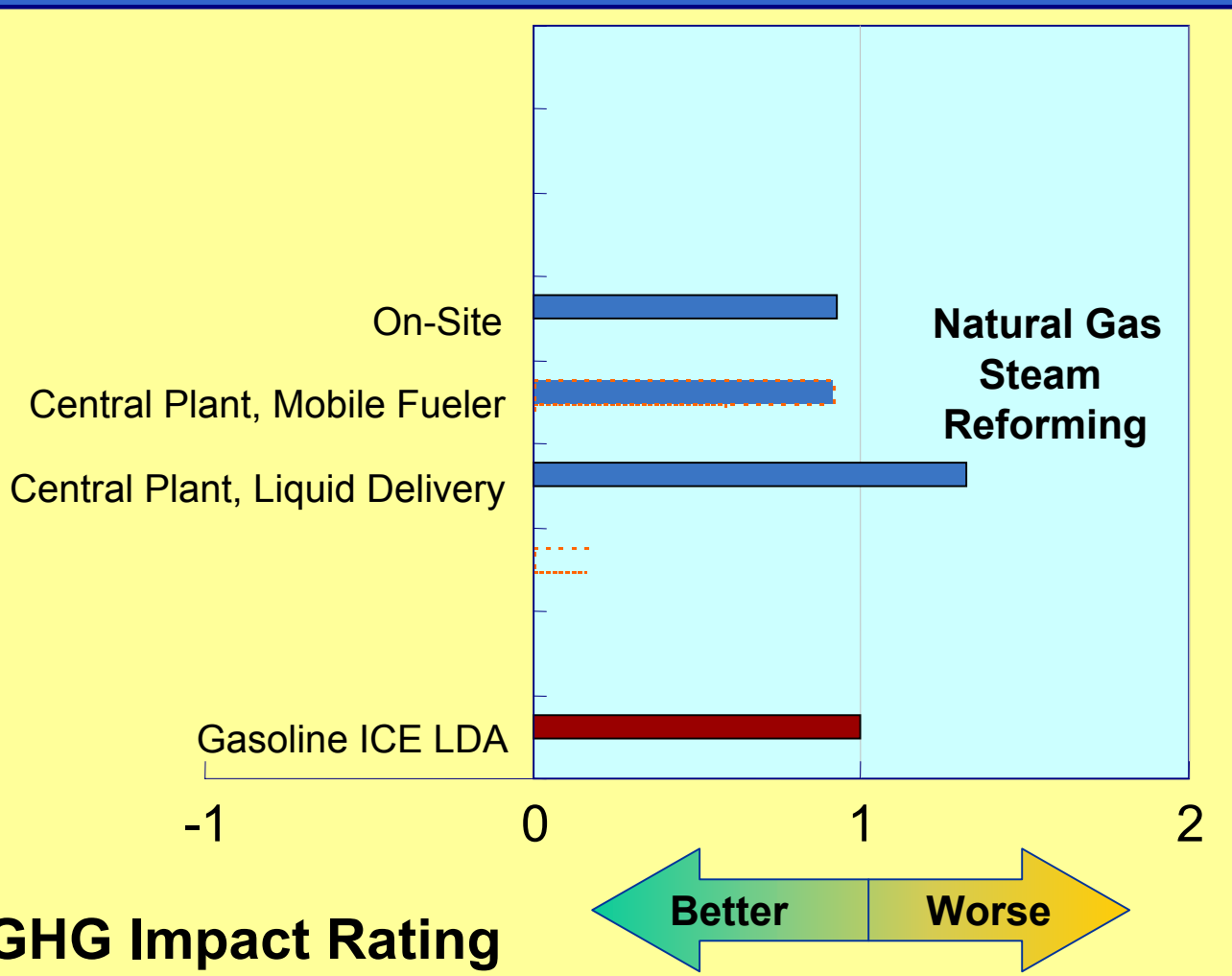


- Normalize gasoline ICE vehicle results to 1
- Lower rating = lower emissions

GHG Ratings ICE Passenger Cars

Hydrogen Vehicles

ICE Car

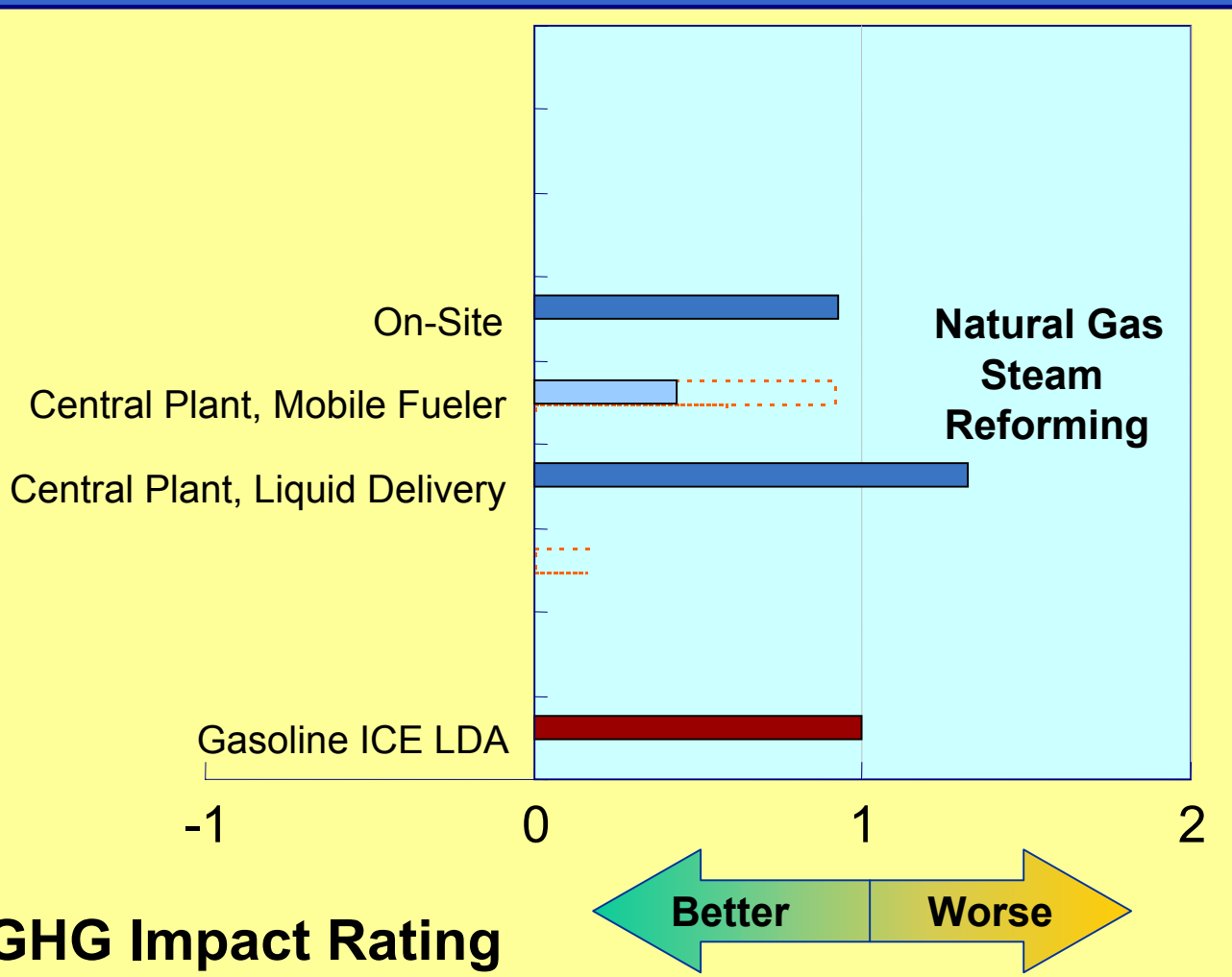


- Fuel economy

GHG Ratings ICE Passenger Cars

Hydrogen Vehicles

ICE Car

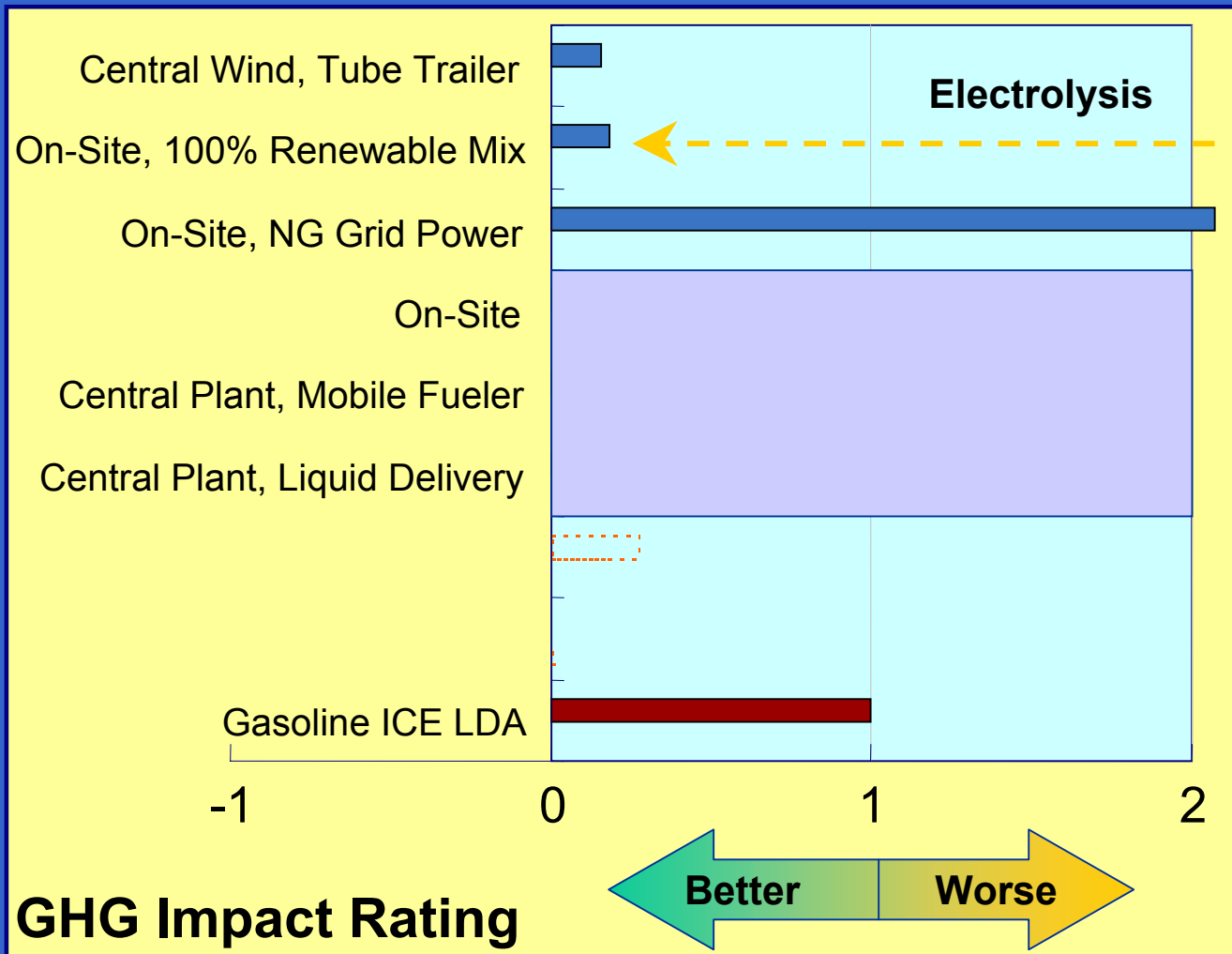


- Fuel economy
- Sequestration

GHG Ratings ICE Passenger Cars

Hydrogen Vehicles

ICE Car

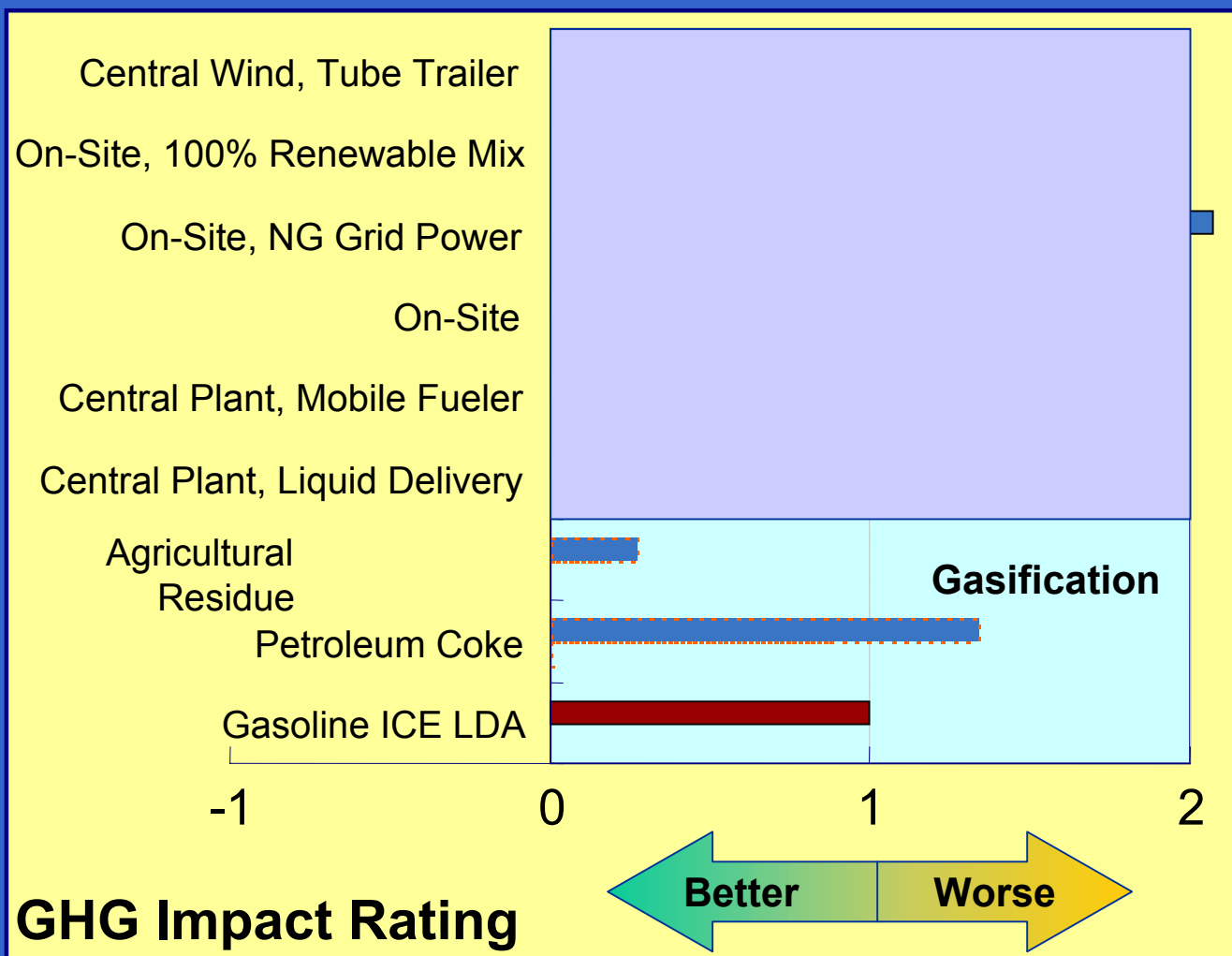


- Fuel economy
- Sequestration
- Renewables

GHG Ratings ICE Passenger Cars

Hydrogen Vehicles

ICE Car

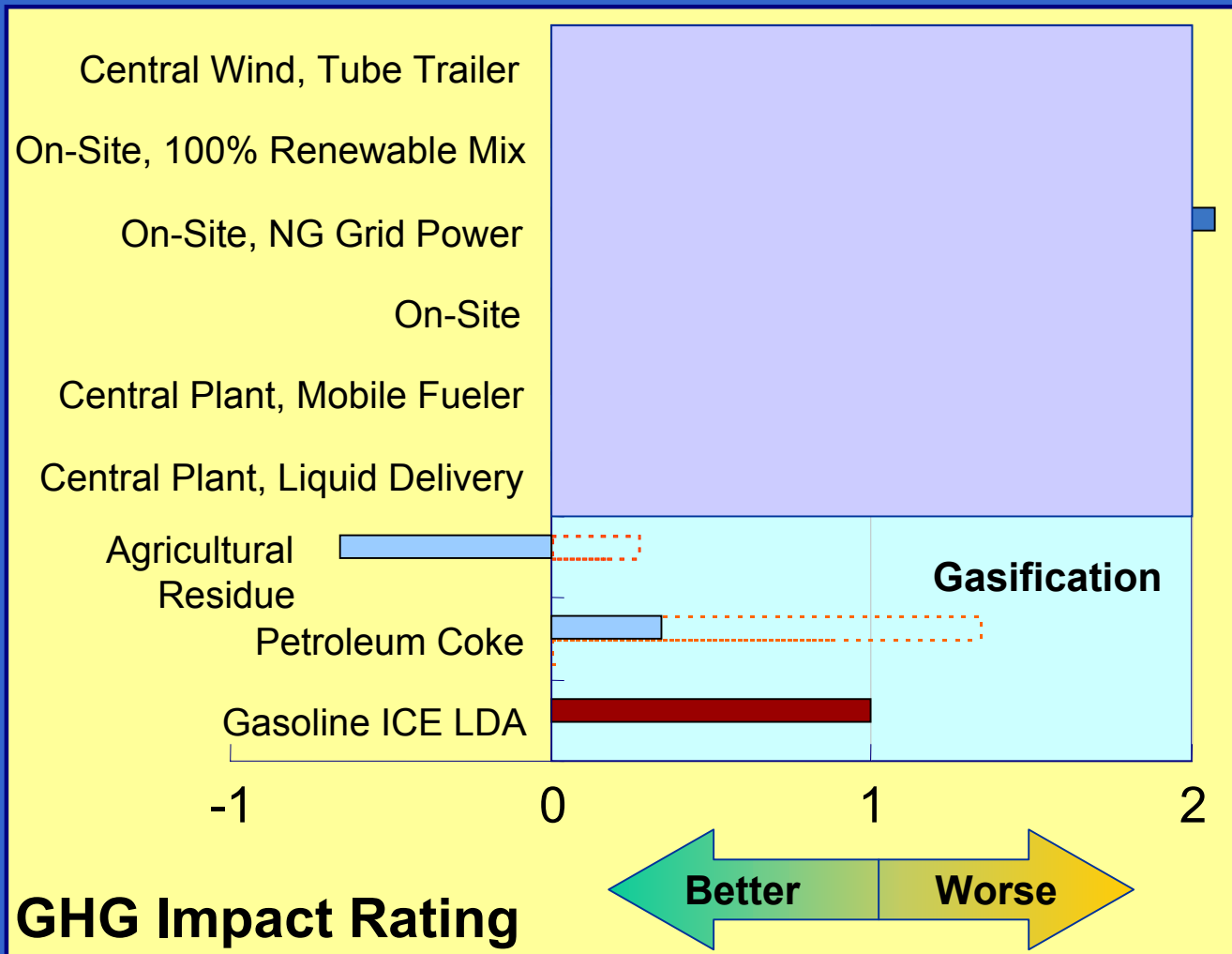


- Fuel economy
- Sequestration
- Renewables

GHG Ratings ICE Passenger Cars

Hydrogen Vehicles

ICE Car

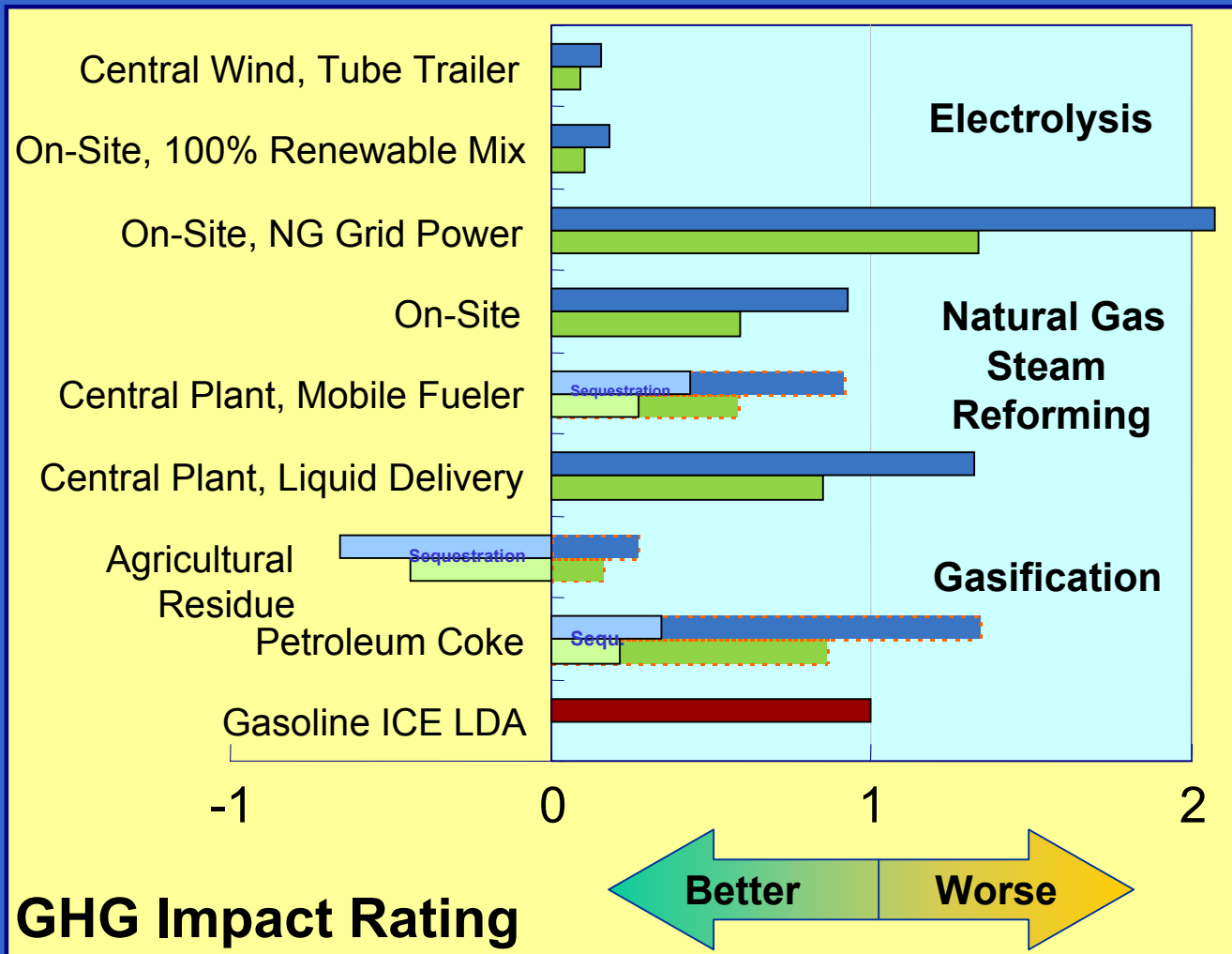


- Fuel economy
- Sequestration
- Renewables

GHG Ratings for Passenger Cars

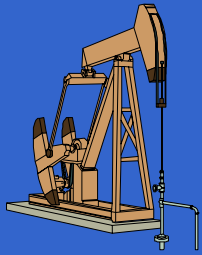
Hydrogen Vehicles

ICE Car
Fuel Cell Car

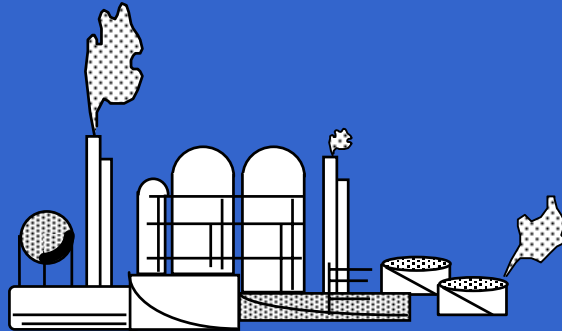


- Fuel economy
- Sequestration
- Renewables
- No regrets option depends on mix

Criteria Pollutant Emissions



PRODUCTION

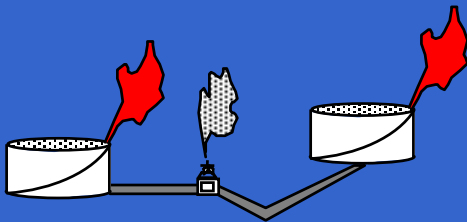


PROCESSING

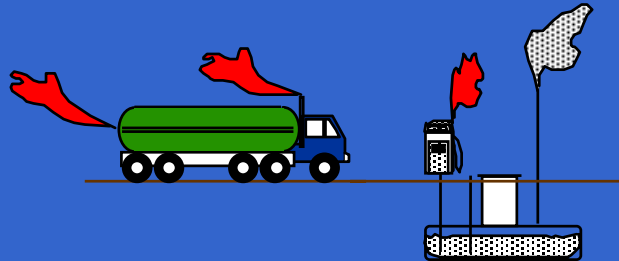
**PRODUCT
STORAGE**



**BULK FUEL
TRANSPORTATION**



BULK STORAGE

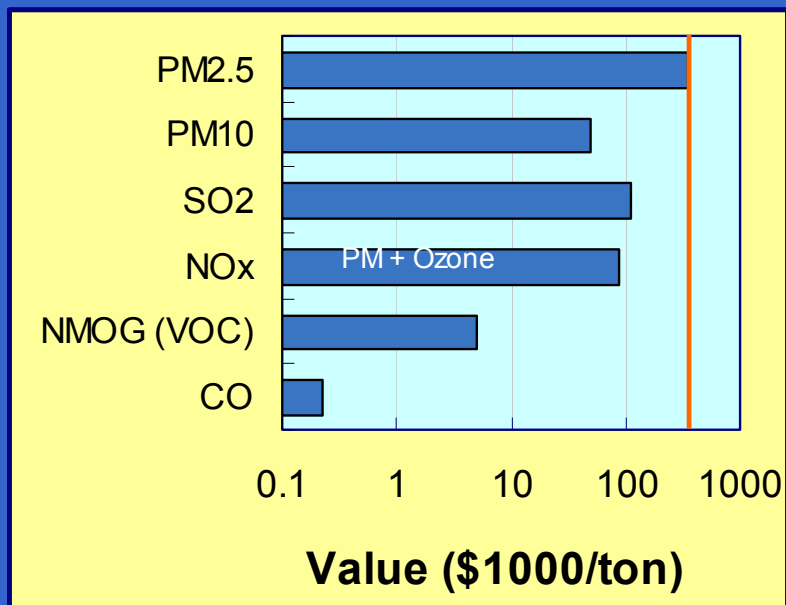


**TRANSPORTATION AND
DISTRIBUTION**

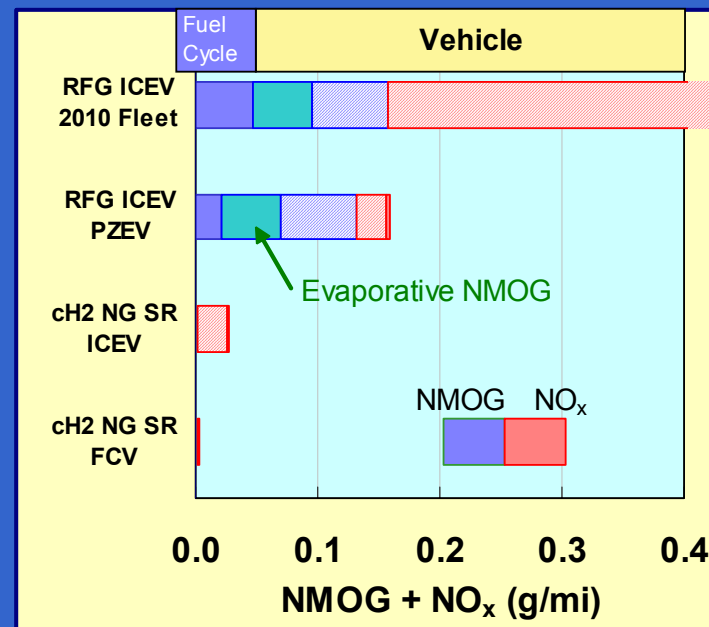


VEHICLE EMISSIONS

Criteria Pollutant Emissions



- Criteria pollutants are weighted according to cost of damages.
- PM2.5 rating = 1.0



- Criteria pollutants include vehicle and fuel cycle
- Fuel cycle depends on vehicle fuel consumption, power plant emissions, etc.

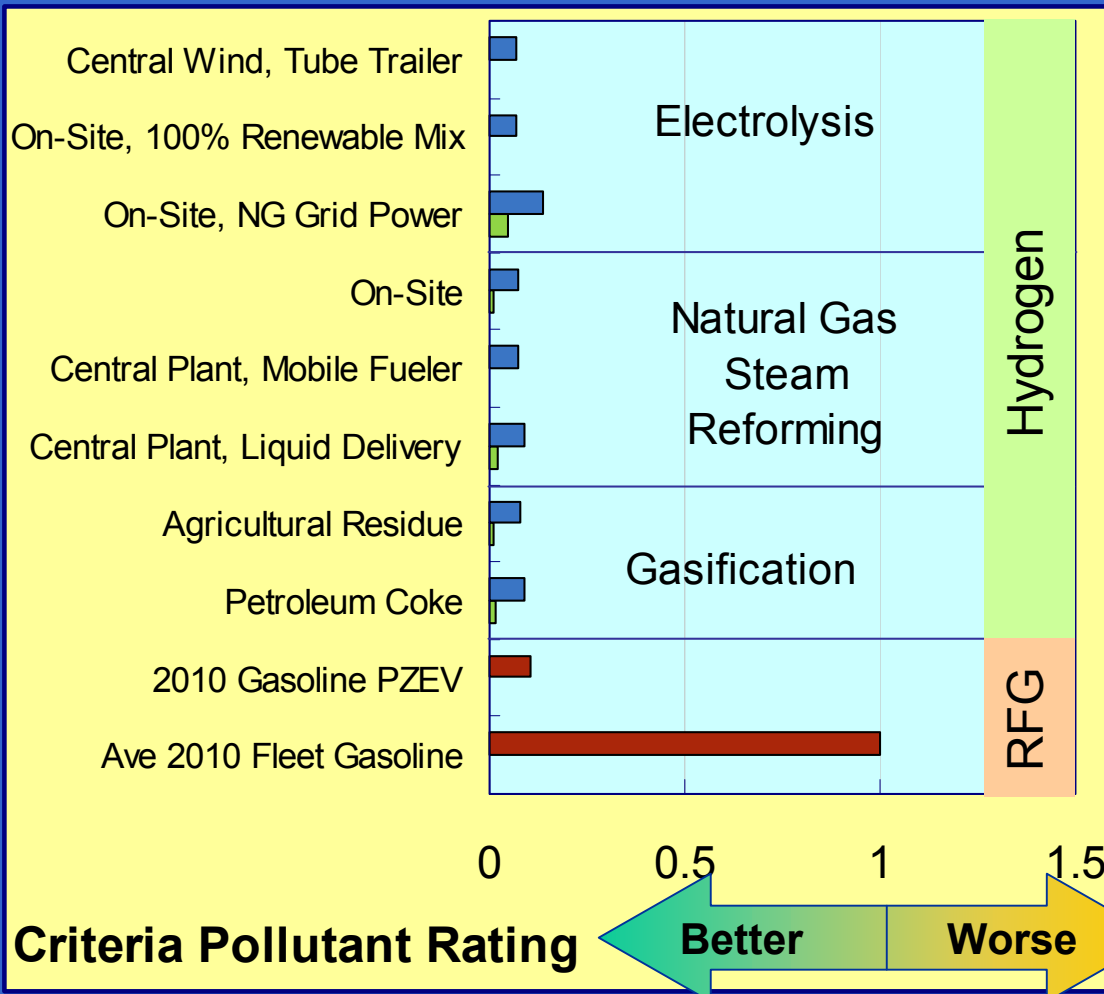
Source: Jackson, M., S. Fable, S. Unnasch, et al., "Benefits of Reducing Demand for Gasoline and Diesel (Task 1)" Consultant report for California Energy Commission and California Air Resources Board, CEC Report P600-03-005A1, May 2003.

Criteria Pollutant Ratings

Hydrogen Vehicles

ICE Car

Fuel Cell Car



Emission Impacts

- Vehicle NO_x
- Power plant emissions

Conclusions

- Energy impacts and GHG ratings depend on:
 - Vehicle fuel economy
 - Zero carbon options – Renewables, sequestration, biomass feedstock
 - Minimal impact strategy is possible by selecting a mix of pathways and energy sources
- Hydrogen criteria pollutant ratings are low compared to 2010 on-road mix



$$\left[\frac{p^2}{2\mu} + V(r) \right] \psi(r) = E \psi(r)$$